

Mechanical Developments for Dynamic Microbeam Radiation Therapy

J. McKinlay on behalf of IMBL team



IMBL applications



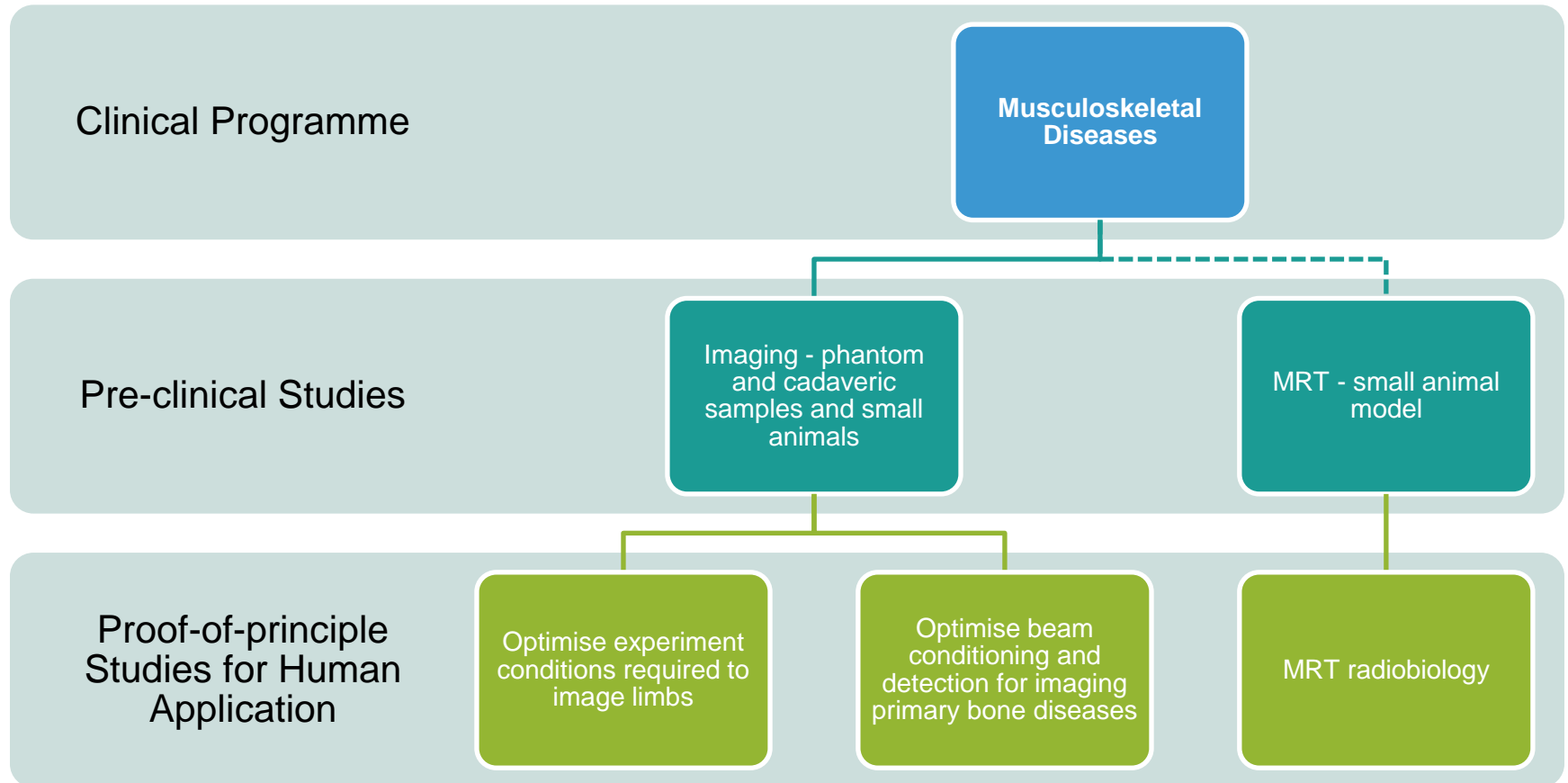
135m - High resolution imaging and computed tomography of samples up to 50cm

An aerial photograph of the IMBL facility. A red line connects the top-left text box to a building in the upper left. Another red line connects the bottom-left text box to a building in the lower left. A third red line connects the bottom-right text box to a large, curved building on the right. The facility includes several buildings, a large parking lot, and green spaces.

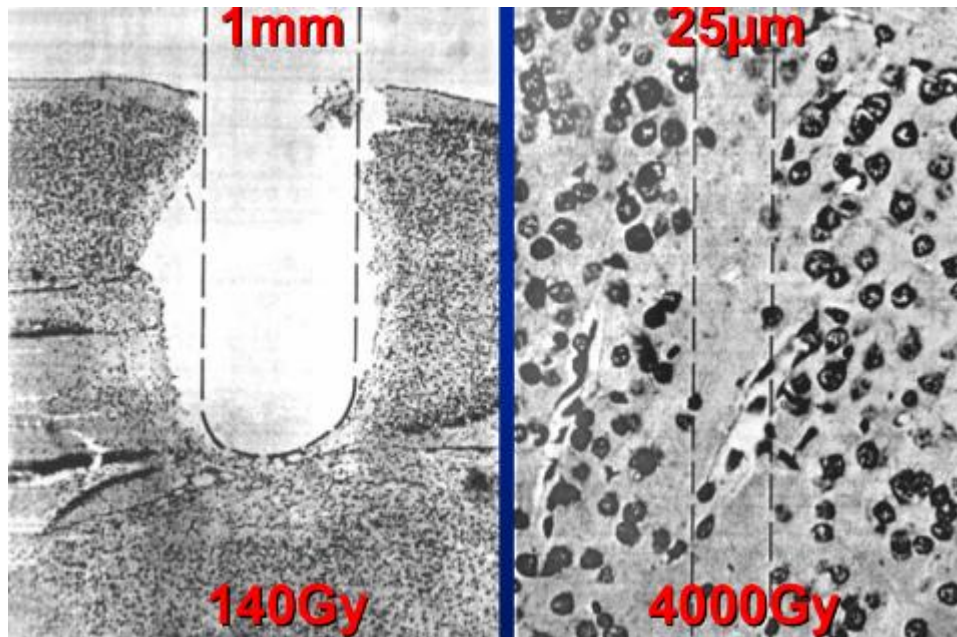
35m - Fast imaging and computed tomography of samples up to 20cm

20m - High dose irradiation

CLINICAL PROGRAM PLAN

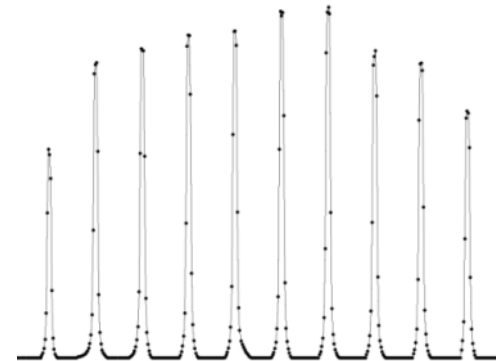
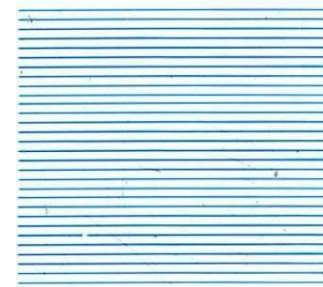


Microbeam Radiation Therapy (MRT)

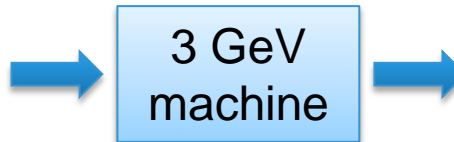


Dose-volume effect

Zeman et al, 1961

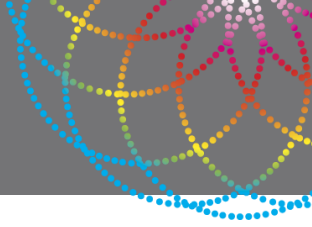


- Wide beam with limited roll-off
- High dose rates >1000 Gy/s
- High peak energy ~ 100 keV



- 4 Tesla Superconducting Wiggler
- 5.2cm period $\Rightarrow K = 19.4$
- Critical energy = 24.5 keV
- Total power = 29 kW
- First filters @ 15 m from source > 100 W/mm²





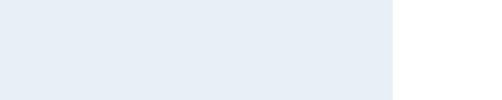
Areas of Development



- Filter selection and design for high heat loads & power densities
- Fast, reliable shuttering for MRT exposures in Step&Shoot mode
- Methods to increase useable beam area (dose uniformity)
- Integrated MRT platform as part of proof-of-principle demonstration

High Power Filtering



Filter Material	W/m.K	Isotropic	Sizes available	Cost	Effect on beam quality	
Diamond	v high	yes	< 80mm dia <600 micron thick	very high	none	
Silicon Carbide	high/med	yes	CVD up to several mm sintered >3mm	high	none	
Industrial (EDM) Graphite	med/low	yes	unlimited	low	nothing observed, may depend on grade	
Expanded/Flexible Graphite	med/low	no	large sheets, up to 5+ mm thick	low	anomalous attenuation values	
Highly Oriented Pyrolytic Graphite	v high/v low	no	up to 80 x 5	high	defracts strongly	
???						

?

Graphene* – the super material



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Coronene
MoS2
WS2
Boron Nitride (BN)
CVD Graphene
Graphene
Coatings/Films
Graphene

Conductive Graphene Sheets, 8"x4"



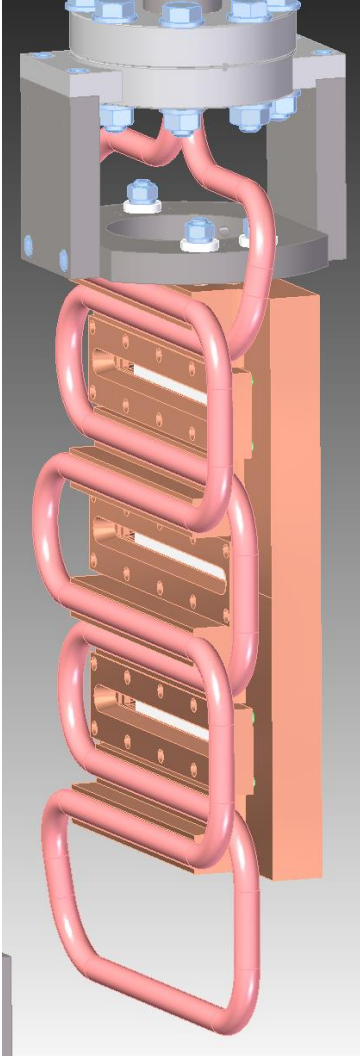
5 pieces of 8"x4" conductive graphene sheets **\$125**

Properties

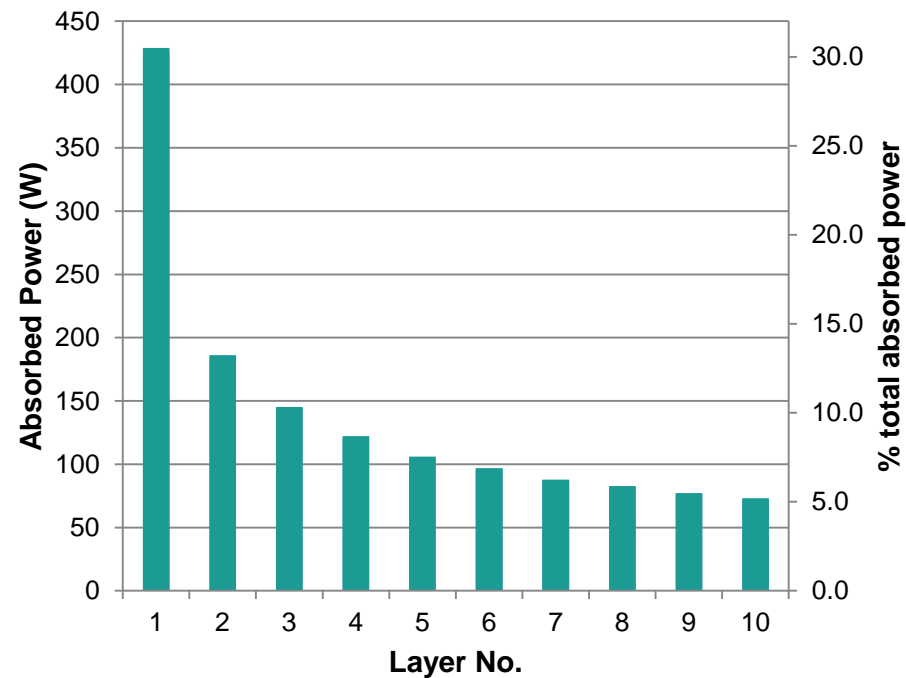
- Size: 8"x4"
- Carbon Content: 97%
- Thickness: 25 micrometers
- Density: 2 g/cm³
- Thermal Conductivity: x-y plane, 1300-1500 W/(m)x(k); z plane, 13-15 W/(m)x(k)
- Tensile Strength: 30 MPa
- Sheet Resistance: 2.8×10^{-2} ohm/square

* may not strictly qualify as graphene if you're a materials scientist

Design of graphene filter holder



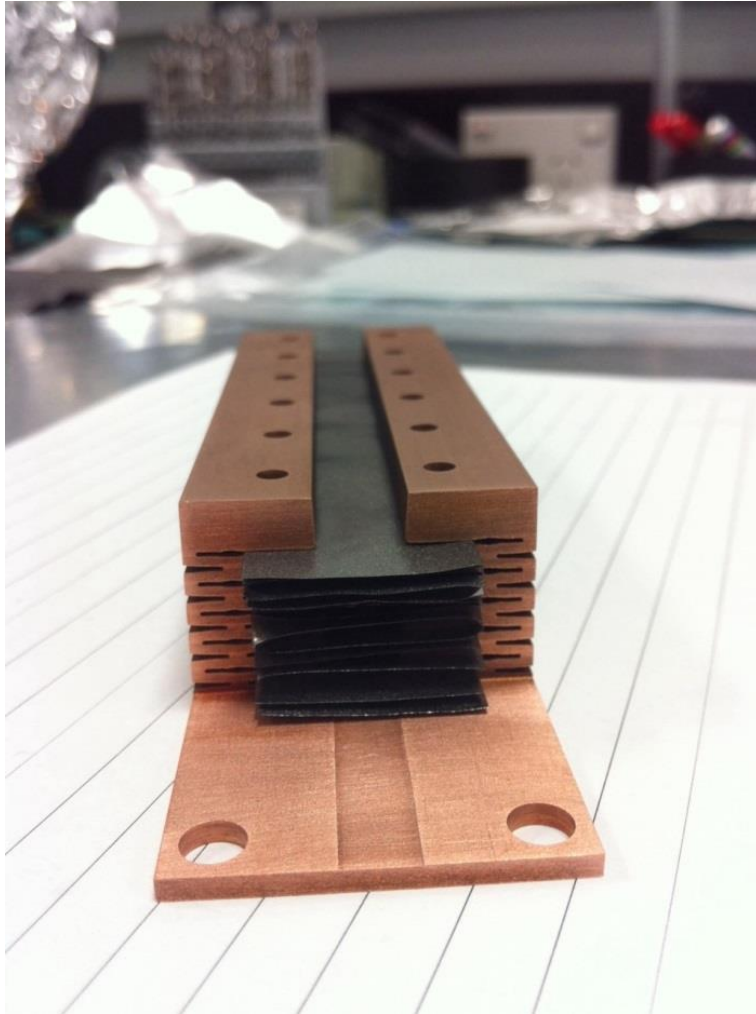
- Compatible with existing filter paddle
- Limited space available
- 1, 9 & 18 layer versions trialled



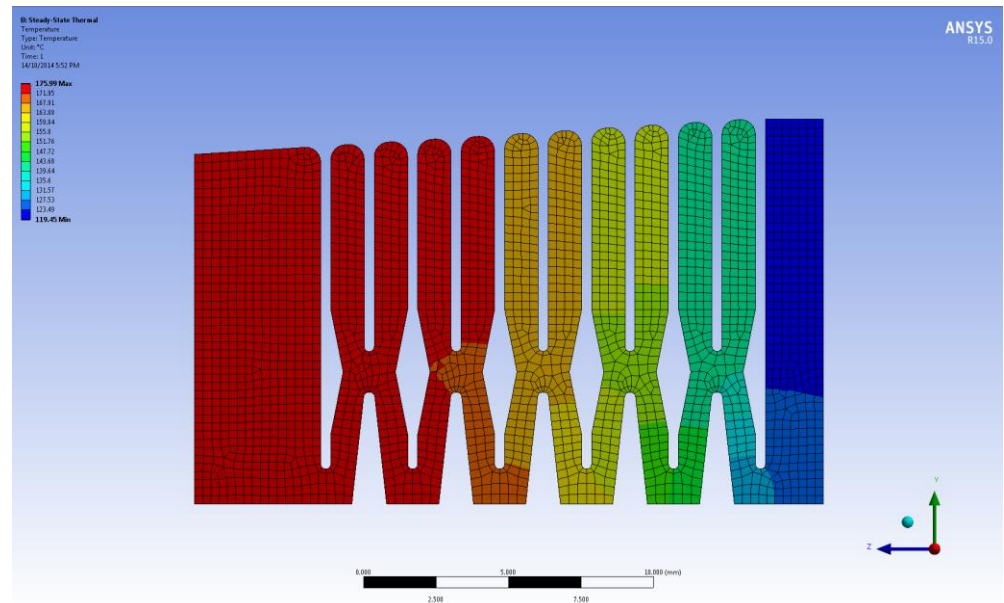
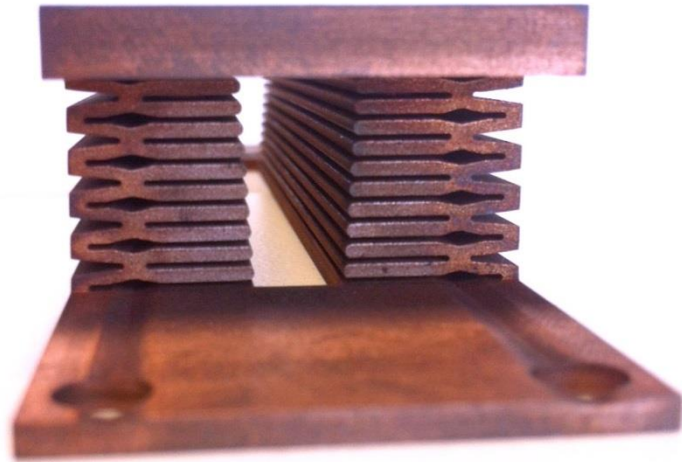
10 layers
- 1.4 kW absorbed
- last layer 5.2%

20 layers
- 1.9 kW absorbed
- last layer 2.6 %

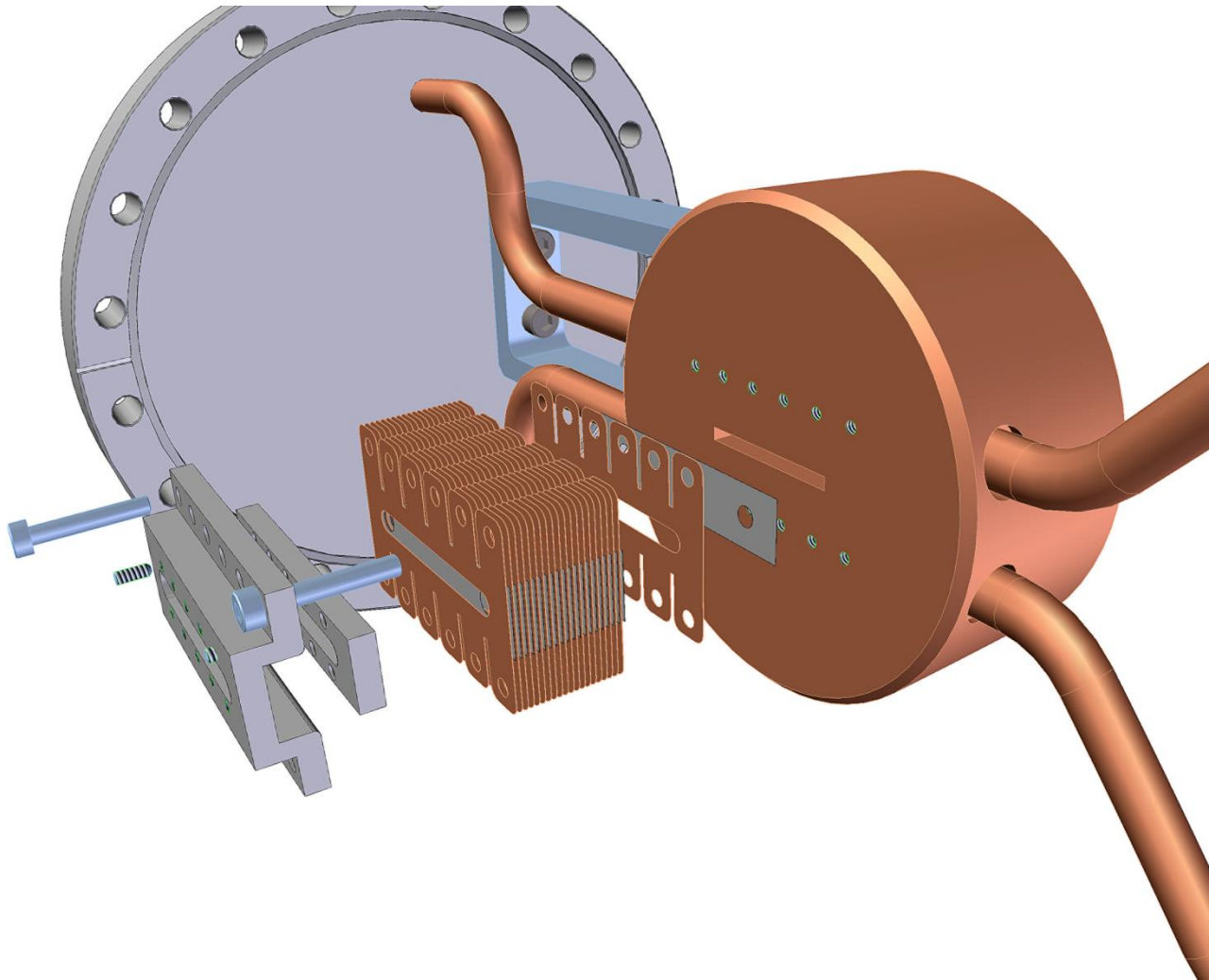
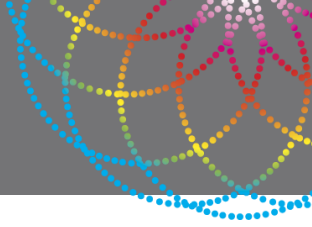
Design of graphene filter holder – cont.



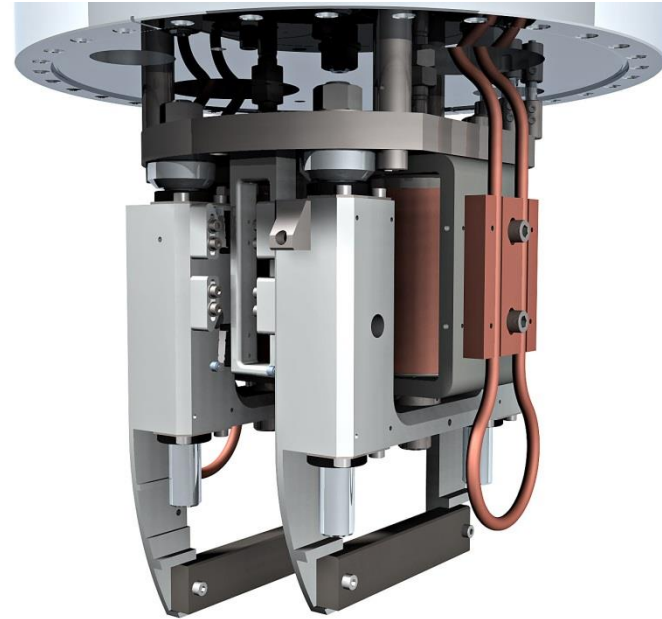
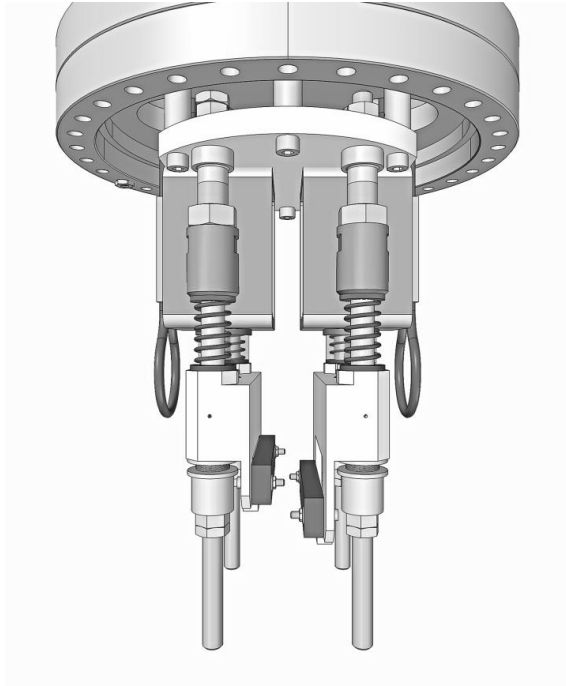
Design of graphene filter holder – cont.



Concept Design for Graphene Filter



Fast & Reliable Shuttering

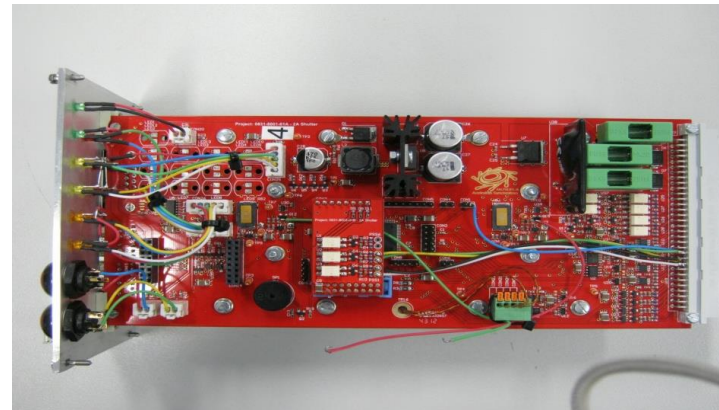


Original design based on ESRF version

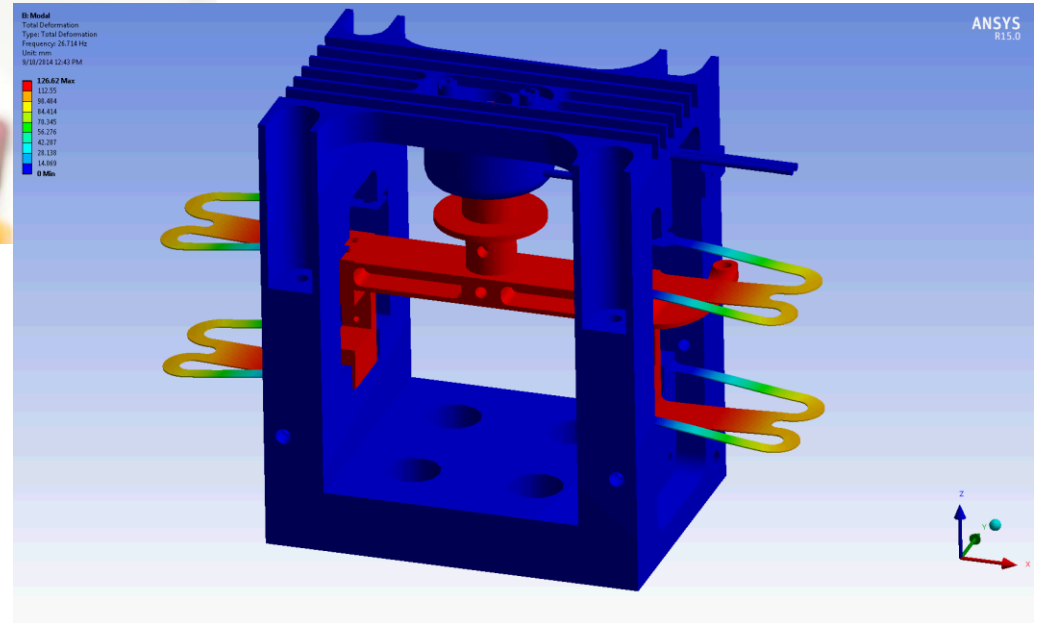
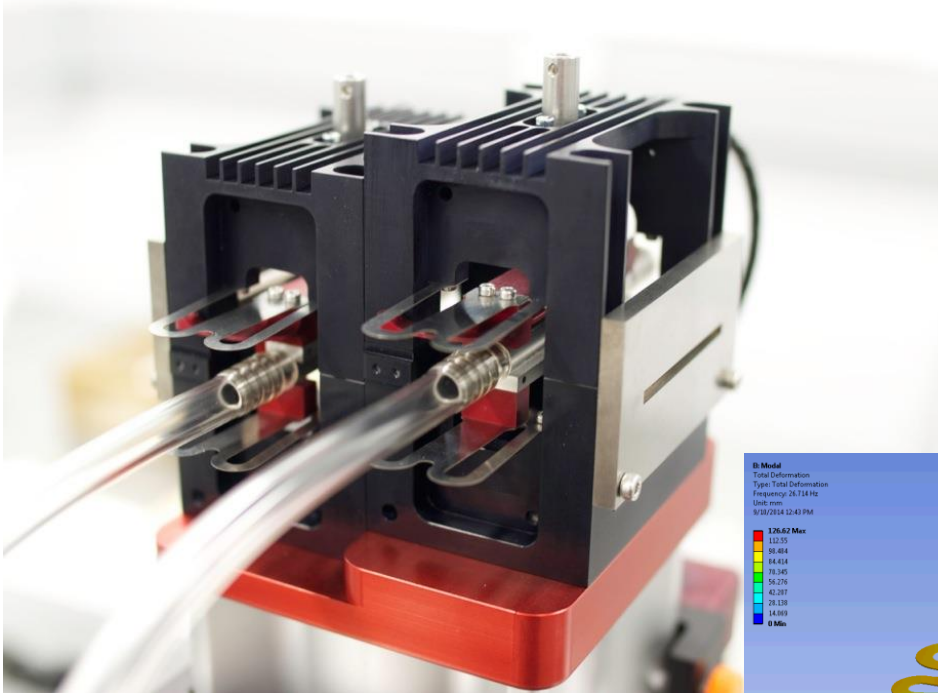
Replaced with more robust design and generic solenoid driver board

Very good timing performance but some problems with bearings

> 2.5 million exposures (estimated)

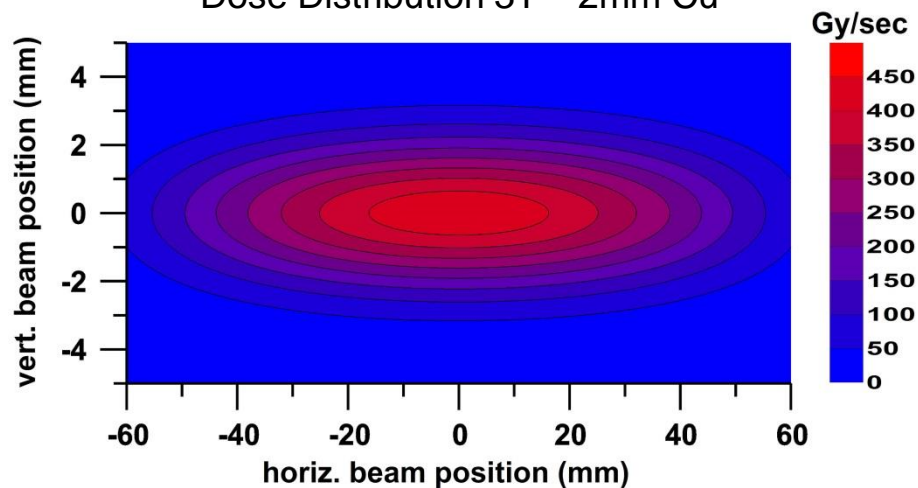


Fast & Reliable Shuttering – cont.

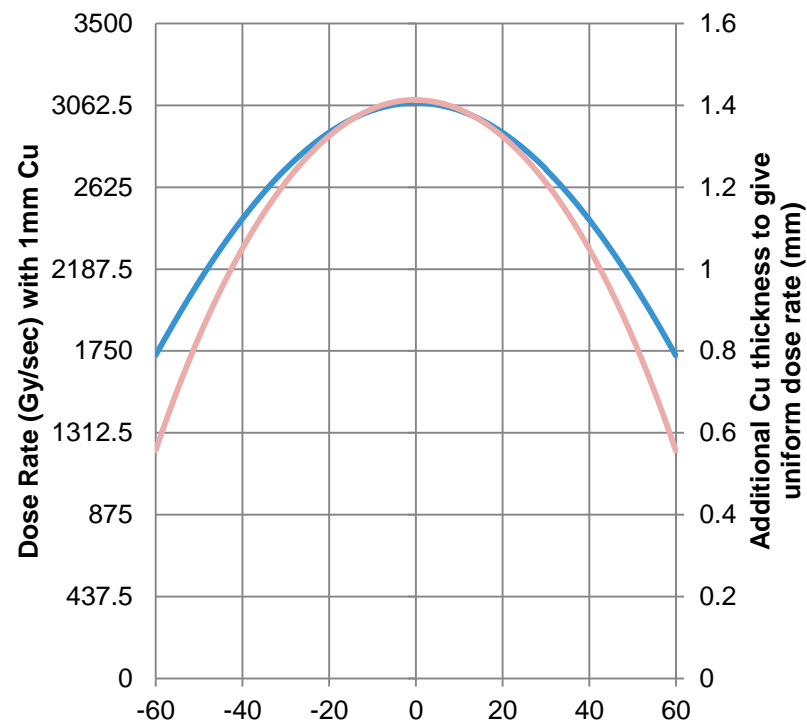
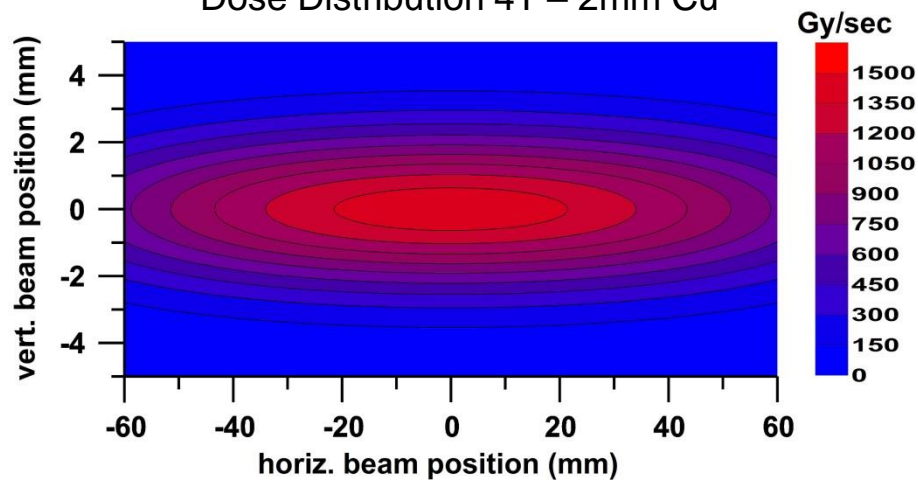


Filter Profiling

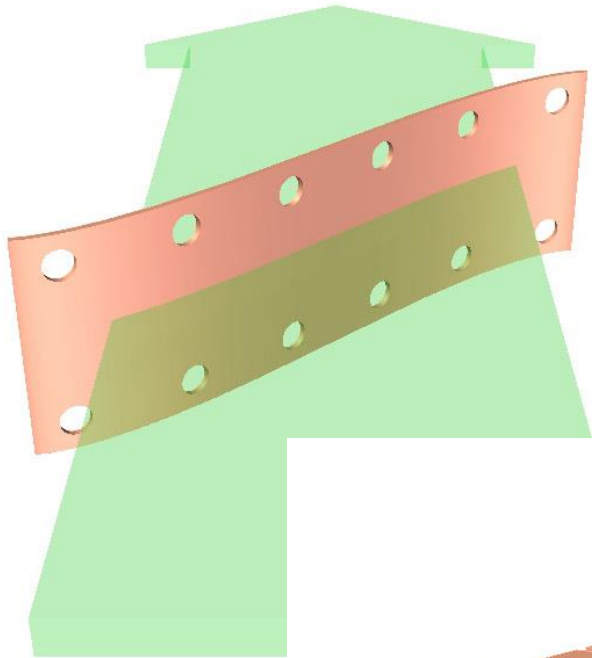
Dose Distribution 3T – 2mm Cu



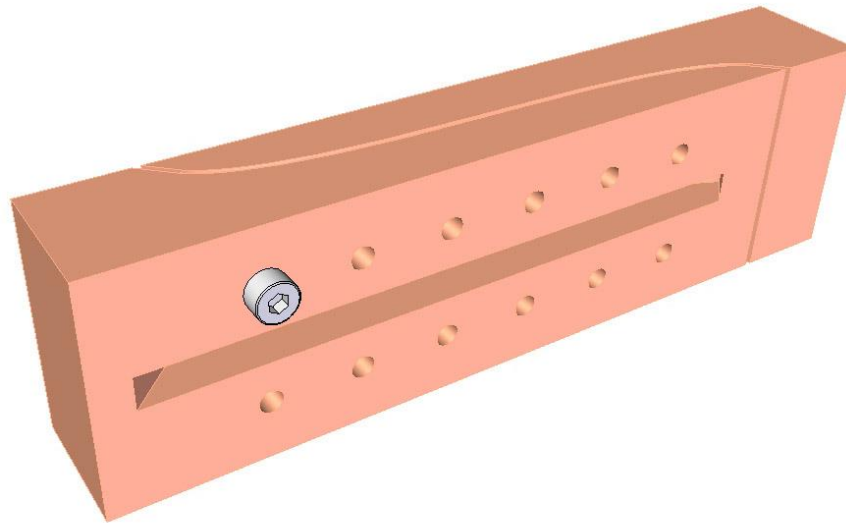
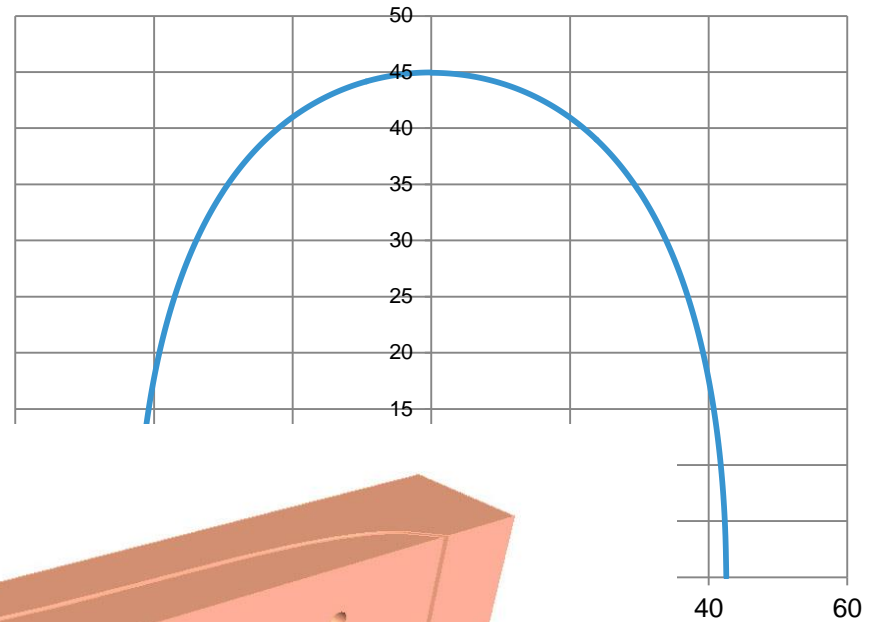
Dose Distribution 4T – 2mm Cu



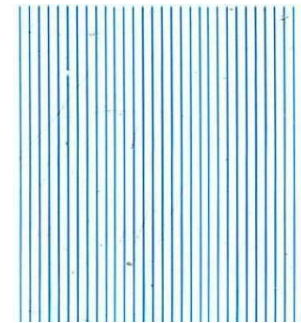
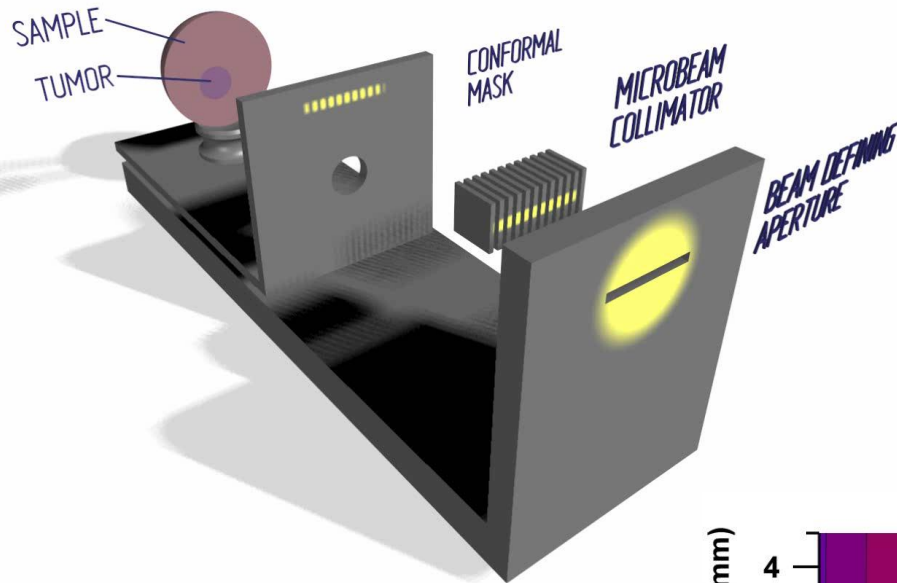
Filter Profiling – cont.



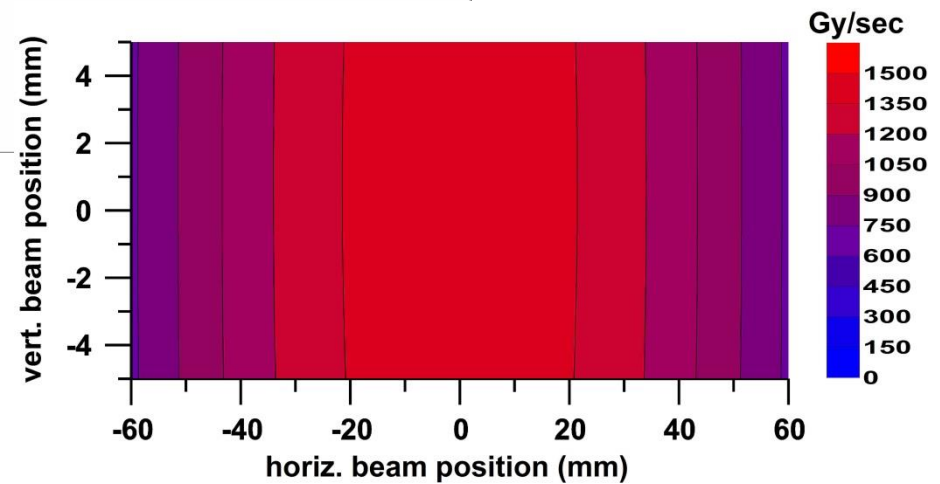
Angle to give calculated thickness



Dynamic (Scanning) MRT



Vertical microbeams



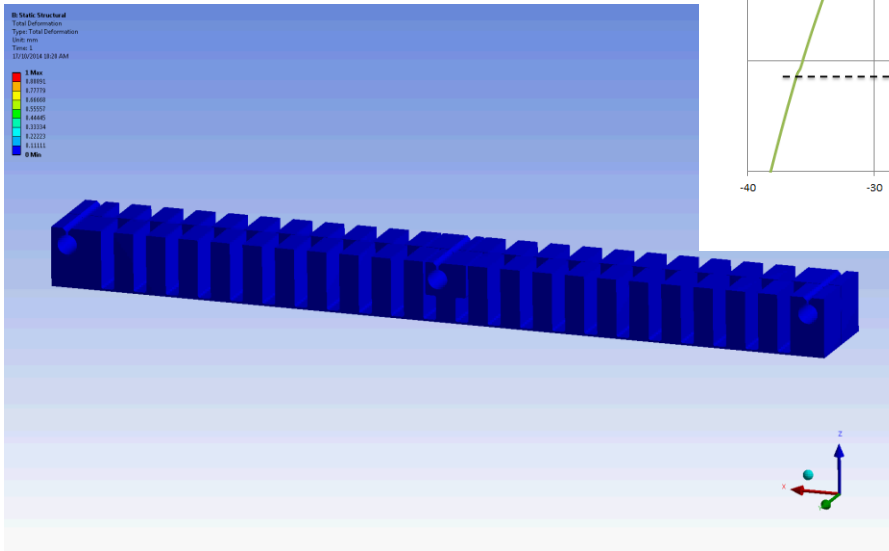
Exposure Profiling

Dose Rate set by wiggler and filters
Delivered Dose = Dose Rate x Exposure Time
Exposure Time = Slit Height x Scan Speed

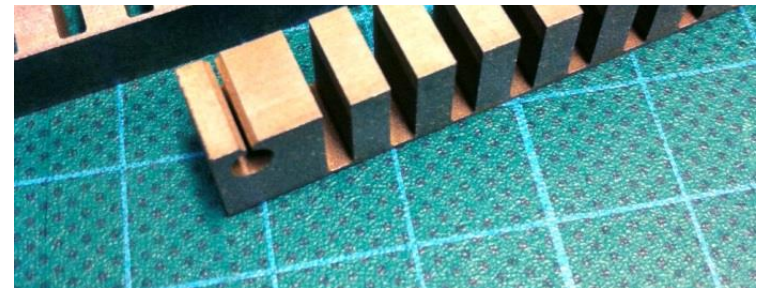
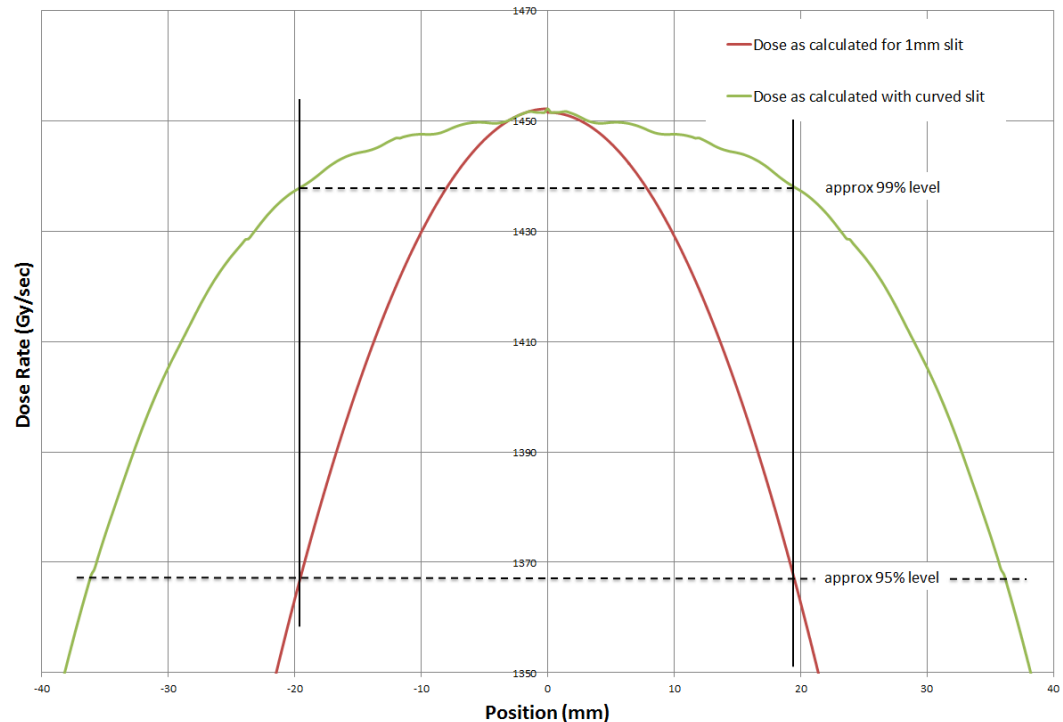
Dose Rate is not uniform across beam

Compensate by non-uniform slit height

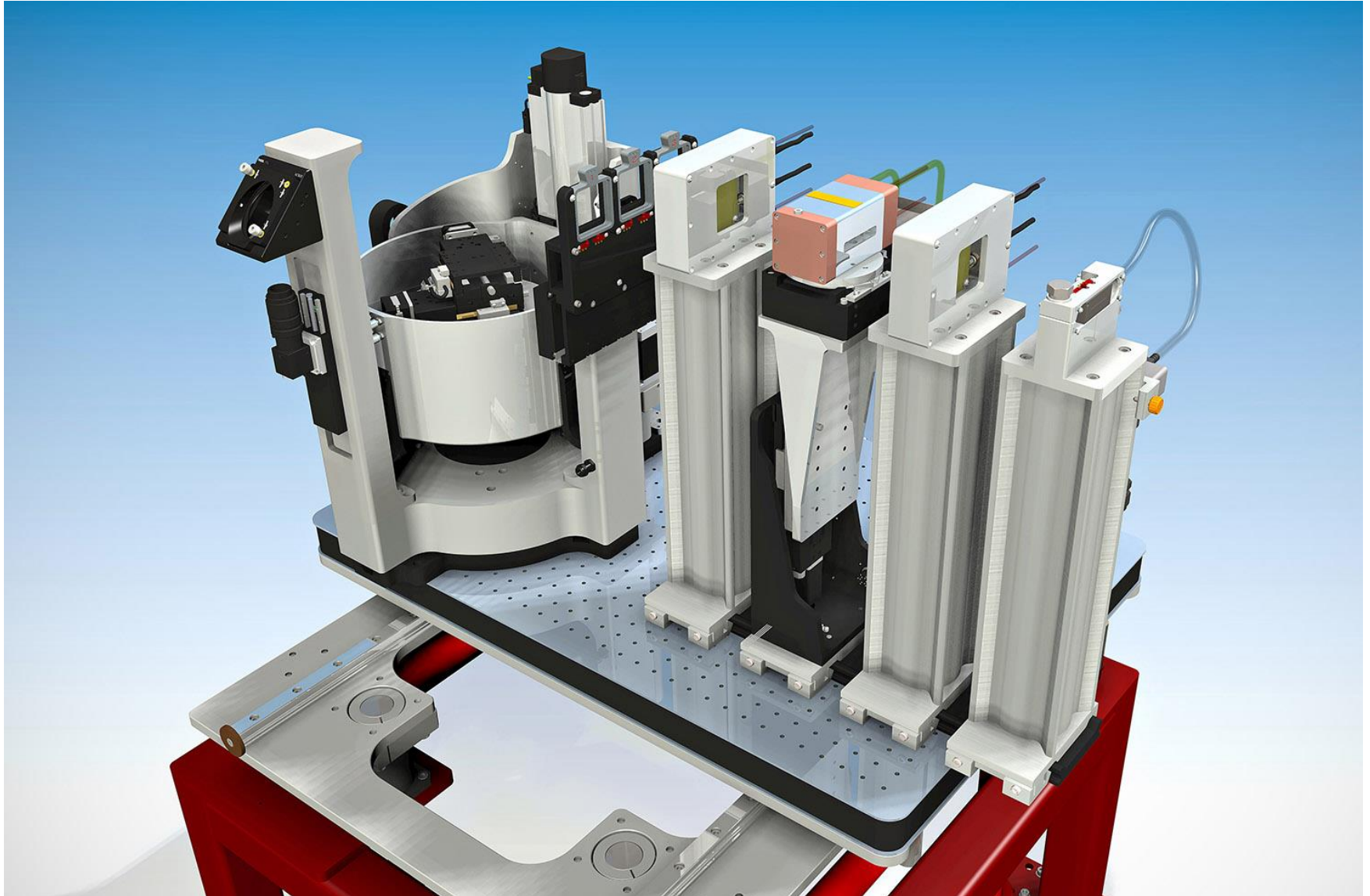
➡ Bendable Tungsten slit blade



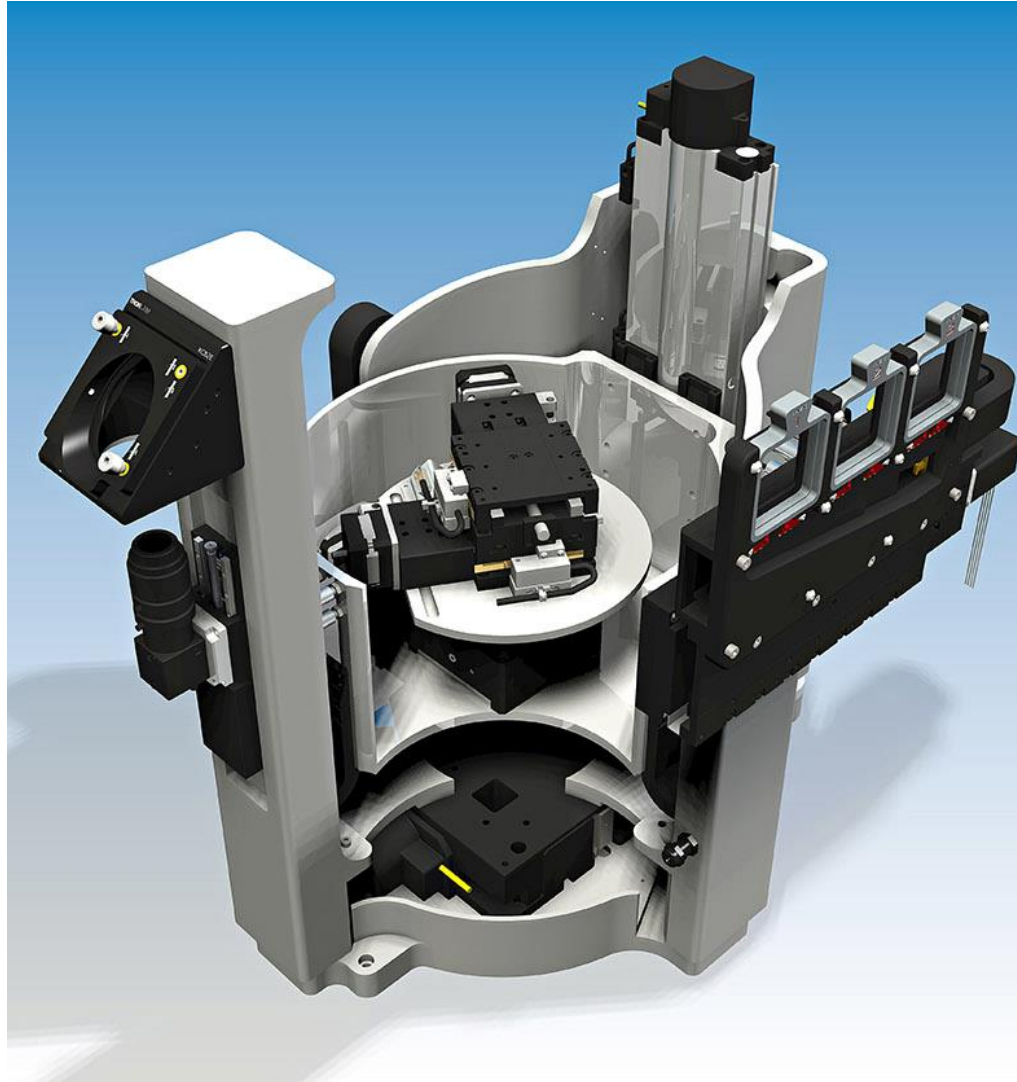
Dose Profiles with Parallel and Curved Slits



Dynamic MRT Endstation Assembly



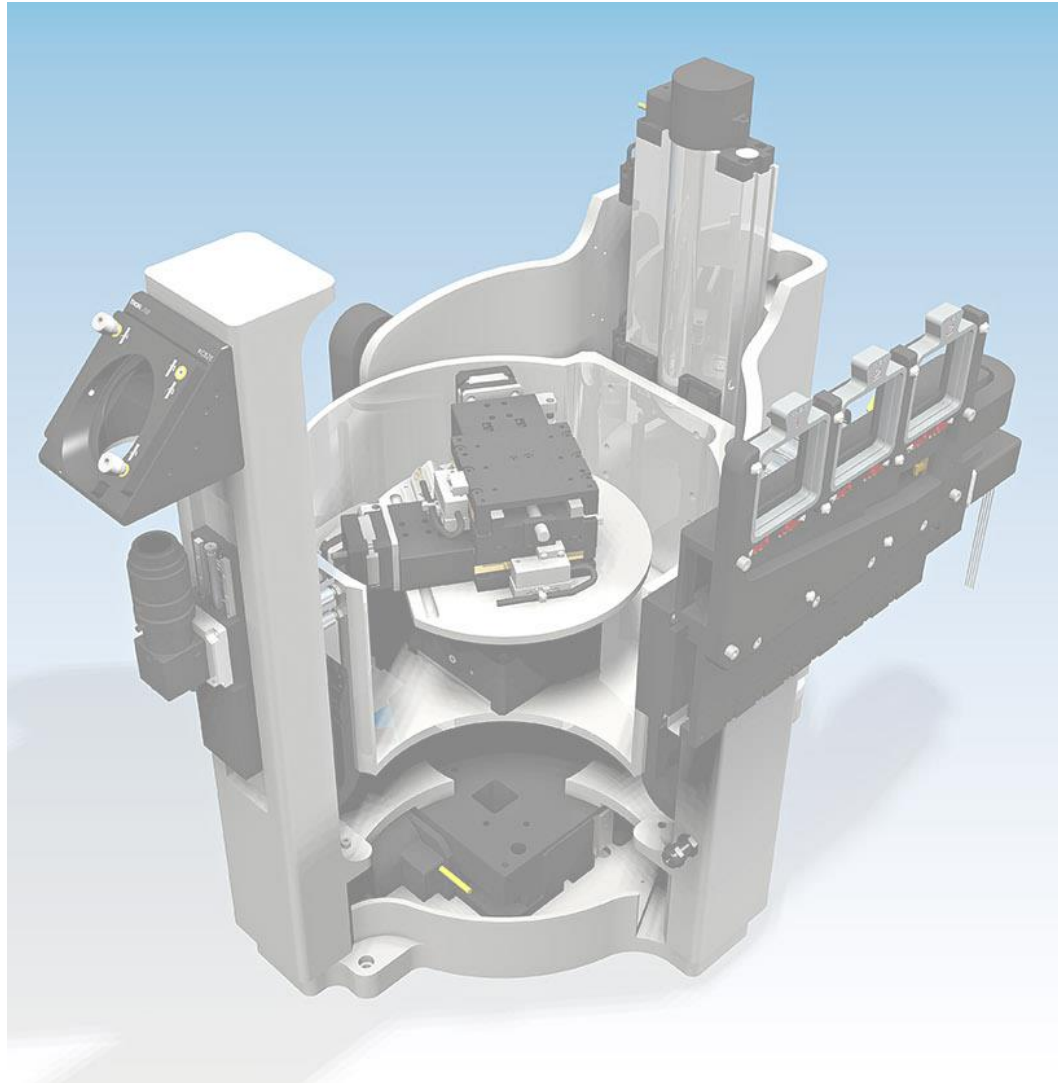
Dynamic MRT Sample Stage



Self-contained MRT stage including

- 3 unique conformal mask positions
- Sample positioning in X, Y & Z
- In built camera system for image guided sample positioning
- Sample rotation stage for two different irradiation angles
- Angle position switch system that automatically interlocks each mask with the associated user-settable irradiation angle and corresponding camera view angle
- Entire upper assembly moves to scan sample through beam so there is no possibility of components losing relative alignment
- Prototype of **Patient Safety System** that monitors all axes during irradiation for any change from set points via 5 encoders and 11 pairs of precision limit switches

Acknowledgements



Thank you to all the people, both at the Australian Synchrotron and at many facilities around the world, who are helping us to design, build, install, operate, repair, replace and improve the many components that go into making this unique beamline.